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Food processing and its association with dental caries: Data from NHANES 2011-2014

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Abstract

Objective: To assess whether proportional contribution of unprocessed or minimally processed, processed or ultra-processed foods to daily energy intake is associated with dental caries in US adults.

Methods: This secondary cross-sectional analysis included adults aged 20 to 59 years old with complete oral examinations, using data gathered from cycles 2011-2012 and 2013-2014 of the continuous National Health and Nutrition Examination Survey (NHANES). Dietary recall data were categorized according to the NOVA classification into four groups: unprocessed or minimally processed foods (Group 1), processed culinary ingredients (Group 2), processed foods (Group 3) and ultra-processed foods (Group 4). The proportional contribution of each of these groups to mean daily energy intake was calculated and then cut into quartiles (Group 1, Group 3 and Group 4) or tertiles (Group 2). Two separate measures were used to assess dental caries: the decayed, missing, filled teeth (DMFT) index and, after exclusion of edentulous participants, prevalence of untreated caries. Poisson regression was used to model DMFT, while logistic regression was used to model the prevalence of untreated dental caries. Models were calculated for each NOVA group. All models were controlled for age, gender, race/ethnicity, level of education, income, access to oral health services, body mass index, smoking status and total energy intake. Analyses took into account NHANES sampling weights.

Results: We analysed data from 5720 individuals, of whom 123 (2.2%) were edentulous. Mean DMFT was 9.7 (± 0.2), while the prevalence of untreated dental caries was 26.0%. Mean daily energy intake was 2170 kcal (± 17). Mean contribution to overall daily energy intake was 28.6% (± 0.5) for G1 foods, 4.3% (± 0.1) for G2 foods, 10.1% (± 0.2) for G3 foods and 56.9% (± 0.5) for G4 foods. A higher intake of G3 was associated with lower DMFT at the fourth quartile (0.89; 95%: CI 0.81-0.96), while a higher intake of G4 was associated with a higher DMFT at the fourth quartile (1.10; 95% CI: 1.04-1.16). In the adjusted models for untreated dental caries, no statistically significant associations were found with any of the NOVA groups.

Conclusion: Higher proportional intake of NOVA groups is only weakly associated with dental caries. Widespread exposure to a highly ultra-processed diet may explain these weak associations.

KEYWORDS
adults, caries, epidemiology, nutrition

1 | INTRODUCTION

Food processing has changed dietary patterns across the globe, with processed and ultra-processed foods contributing to an ever-increasing share of the energy intake of populations.[1,2] Classifying foods in accordance with their level of processing improved the understanding of these new patterns and enabled the systematic assessment of how they might contribute to diet-related conditions and noncommunicable diseases.[3] A diet rich in ultra-processed foods is poorer in quality, with less protein, fibre, vitamins and micronutrients and more added sugars.[4-7] In terms of health outcomes, they cause weight gain[8] and are associated with cancer,[9] metabolic syndrome,[10] hypertension[11] and all-cause mortality.[12,13]

Diet is strongly associated with dental caries. The intake of added sugars is a particularly important risk factor for caries, with evidence pointing to the significance of controlling both amount and, to a lesser extent, frequency of its intake.[14,15] Studies suggest a moderate effect of refined starches and a negligible effect of whole starches and whole fruits on the development of dental caries.[16] Ultra-processed food intake is very strongly associated with free sugars intake.[4,6,7] Even though the most consumed ultra-processed foods are not those typically associated with caries, studies show that a reduction in the proportional daily energy contribution (%E) of these foods would entail a reduction in sugar intake and an increase in the intake of less cariogenic foods.[4,6] In this sense, restricting ultra-processed intake could be a good strategy to help meet the World Health Organization (WHO) recommendations on sugar intake.[17]

New nutritional guidelines take processing into account, particularly by using the NOVA (not an acronym) classification and focusing on reducing the dietary contribution of ultra-processed foods.[18] Vast literature on a variety of foods and drinks and their association with dental caries is available.[14,16,19,20] Nevertheless, the relationship between different levels of food processing with dental caries has not been systematically investigated. Thus, with this study we aimed to assess whether proportional contribution of unprocessed or minimally processed, processed or ultra-processed foods to daily energy intake is associated with dental caries in USA adults.

2 | METHODS

2.1 | Population and sample

This secondary analysis used cross-sectional data from two cycles of the continuous National Health and Nutrition Examination Survey (NHANES): 2011-2012 and 2013-2014. These data were obtained using a complex, multistage probability sampling design, and they are representative of noninstitutionalized civilian residents in the United States of America in the midpoint of the two cycles included in the analysis.[21] We have restricted our study population to adults aged 20-59 years old with a complete oral examination record (a comparison with participants with incomplete examination is presented in Supplement S1) and two 24-hour dietary recalls, in accordance with age cut-points proposed by the NHANES analytic guidelines.[21] A flow chart detailing our studied population is presented in Figure S1.

2.2 | Data collection

Participants were first interviewed at home, completing a screener questionnaire, then a series of structured questionnaires which were applied according to sample eligibility. Data collected at this time included sociodemographic background and health history. Participants were then referred to attend a mobile examination centre (MEC), where physical examinations, laboratory tests and a dietary interview were performed. Three to 10 days after the MEC examinations, participants were contacted by telephone and invited to do a follow-up dietary interview. This dietary interview aimed to obtain detailed information on dietary intake from selected participants. These data were used to estimate consumption of types and amounts of foods and beverages, including their energetic and nutritional components. Portion size estimation is further explained in the NHANES dietary interview manuals.[22]

2.3 | Food classification

Food items recorded in these dietary recalls were classified according to NOVA, a system of food classification based on the extent and purpose of industrial food processing.[23] This classification divides foods into four groups: unprocessed or minimally processed foods; processed culinary ingredients; processed foods; and ultra-processed foods. Unprocessed or minimally processed foods, also referred to as group 1 (G1) foods, are edible parts of plants, animals, fungi or algae, either in their natural state or after being altered by processes such as removal of inedible or unwanted parts, drying, crushing, grinding, fractioning, filtering, roasting, boiling, pasteurization, refrigeration, freezing or nonalcoholic fermentation. These processes do not add substances such as fats, oils, salt or sugar into the original food. Processed culinary ingredients, or group 2 (G2) foods, are obtained from unprocessed or minimally processed foods through pressing, refining, grinding, milling or spray drying. These ingredients are not usually consumed alone, as they are normally added to G1 foods to cook or season them. Processed foods, or group 3 (G3) foods, are products made by adding G2 ingredients to G1 foods. Most G3 foods have few ingredients, and the processes involved in making them include various preservation or cooking methods. Fermented alcoholic beverages are classified as processed foods. Ultra-processed foods, or group 4 (G4) foods, are industrialized products which normally have five or more ingredients. While these often include ingredients used in processed foods, they also contain substances not commonly used in domestic cooking and additives which have the purpose to imitate taste, smell, or texture of G1 or G3 foods. G1 foods are commonly absent, and if present, represent a small proportion of these G4 formulations. Ultra-processed foods are manufactured with the use of industrial processes that have no domestic equivalents, such as extrusion and moulding and preprocessing for frying.

We have used NHANES provided Food Codes energy values. For hand-made recipes, NOVA was applied to underlying ingredients (Standard Reference Code), while energy values were calculated using variables from the Food and Nutrient Database for Dietary Studies and the US Department of Agriculture National Nutrient Database for Standard Reference. This classification process has been previously described in further depth.[4,24] Energy intakes for each NOVA group were calculated, which was then used to determine the percentage of contribution of each group to total daily energy intake (% E). Participants who did not respond to both dietary recalls were excluded from our analysis.

2.4 | Oral examination

We used two measures of dental caries as outcomes in this study: dental caries experience, represented by the DMFT index and untreated dental caries, which was defined as the presence of at least one surface with a surface condition code 0-4 (ie a carious lesion), or the presence of at least one untreated carious root tip. DMFT was calculated as the total count of codes E, J, K, M, P, Q, R, T, X and Z in the 'Coronal Caries: Tooth Count' segment of the dental examination. Edentulous participants were included in the dental caries experience analyses and assigned a DMFT of 28 (since the crown surface examination protocol excluded third molars). When analysing the prevalence of untreated caries, edentulous participants were excluded. Oral health examinations were conducted by licensed dentists in a room at the MEC using light, compressed air and a portable dental chair. Caries scoring criteria used in the dental examination, along with quality assurance and training/calibration details, are further described in Supplement S1. These processes are described in-depth in the NHANES plan and operations manual.[25]

2.5 | Covariates

Covariates included in our analyses were age, gender, race/ethnicity, level of education, income, access to oral health services and total energy intake. Age was categorized as 20-29, 30-39, 40-49 and 50-59 for bivariable analysis, while it was used as a continuous variable in our models. Education was categorized as 'Less than 9th Grade', '9-11th Grade', 'High School Grad/GED or Equivalent', 'Some College or Associate Degree' or 'College Graduate or Above'. Race/ethnicity was categorized as follows: non-Hispanic white; Mexican American; other Hispanic; non-Hispanic black; non-Hispanic Asian; and Other race (including multi-racial). Income was assessed using the ratio of family income to localized poverty threshold levels. Access to oral health services was evaluated with the use of two variables. The first originated from the question 'When did you last visit a dentist?', which had its answers categorized into 'Within last year', 'More than 1 year but less than 5 years' and 'More than 5 years, never or does not know'. The second originated from the question 'During the past 12 months, was there a time when you needed dental care but could not get it at the time?', with 'Yes' or 'No' as response options. Body mass index (BMI) was categorized into underweight for values <18.5, normal for values ≥18.5 and <25, overweight for values ≥25 and <30, and obese for values ≥30. A smoking status variable was constructed, where participants who answered 'no' to the question 'Have you smoked at least 100 cigarettes in your entire life?' were categorized as 'never smokers'. If they answered 'yes' to this question and 'no' to the question 'Do you now smoke cigarettes?', they were categorized as 'ex-smokers', while, if they had answered 'yes' to both questions, they were categorized as 'current smokers'. In all these variables, 'Refuse' and 'Don't know' were set as missing values.

2.6 | Statistical analysis

NHANES dietary recall day 2 sampling weights were used in all analyses. Daily energy contribution of NOVA groups 1, 3 and 4 was cut into quartiles. Group 2 had to be cut into tertiles as more than 25% of the sample did not recall consuming foods in this group. Proportions were presented as weighted percentages, and means were presented alongside their standard errors. Between-group differences were assessed with the chi-square test for categorical variables and the Mann-Whitney-Wilcoxon or Kruskal-Wallis test (as appropriate) for continuous variables. Logistic regression models were estimated to assess controlled associations between quantiles of energy contribution of each NOVA group and the outcome of prevalence of untreated dental caries. Exponentiated coefficients from these models were presented as odds ratios (OR) with their respective 95% confidence intervals. We used Poisson regression to evaluate associations of NOVA groups with DMFT and number of decayed surfaces, with both outcomes modelled as count variables. DMFT models were offset by the total number of valid examined teeth. The coefficients of these models were also exponentiated and presented as rate ratios (RR) with respective 95% confidence intervals. All models were controlled for age, gender, race/ethnicity, income-to-poverty threshold ratio, level of education, access to oral health services, smoking status, BMI and total energy intake. Participants with missing data (509 in total) were excluded from these models. Analyses were conducted using R 3.6.1 (R Core Team, Vienna, Austria) and the package survey 3.36.[26]

TABLE 1 Mean DMFT score by sociodemographic and health characteristics in the NHANES cycles 2011-2014

	No. participants	DMFT (± SE)	*P*-value
Total		9.7 (0.2)	
Age			
20-29	1432	5.3 (0.2)	
30-39	1432	8.1 (0.3)	
40-49	1442	11.1 (0.2)	
50-59	1414	14.2 (0.3)	<.001[a]
Sex			
Male	2744	9.3 (0.2)	
Female	2976	10.2 (0.3)	<.001[b]
Race/ethnicity			
Non-Hispanic white	2245	10.2 (0.2)	
Mexican American	709	8.5 (0.4)	
Other Hispanic	520	9.6 (0.3)	
Non-Hispanic black	1301	9.3 (0.4)	
Non-Hispanic Asian	724	8.0 (0.3)	
Other race—including multi-racial	221	9.5 (0.6)	<.001[a]
Family Income-to-Poverty Threshold Ratio			
>1	4009	9.6 (0.2)	
≤1	1317	10.5 (0.7)	.512[b]
Education			
Less Than 9th Grade	282	10.0 (0.6)	
9-11th Grade	716	11.6 (0.5)	
High School Grad/GED or Equivalent	1195	10.9 (0.3)	
Some College or Associate degree	1882	9.7 (0.3)	
College Graduate or above	1643	8.5 (0.2)	<.001[a]
Last dental visit			
Within last year	3104	9.7 (0.2)	
More than 1 year but less than 5 years	1760	9.5 (0.3)	
More than 5 years, never or does not know	856	10.5 (0.6)	.516[a]
Could not get dental care (last year)			
Yes	1384	11.6 (0.3)	
No	4234	9.3 (0.2)	<.001[b]
Body Mass Index			
Underweight	99	9.4 (1.0)	
Normal	1670	9.2 (0.4)	
Overweight	1769	9.5 (0.2)	
Obesity	2151	10.4 (0.2)	<.001[a]
Smoking status			
Never smoker	3454	8.5 (0.2)	
Ex-smoker	979	10.7 (0.3)	
Current smoker	1284	12.1 (0.5)	<.001[a]

[a]Kruskal-Wallis test.
[b]Mann-Whitney-Wilcoxon test.

3 | RESULTS

We analysed data from 5720 individuals from continuous NHANES cycles 2011-2012 and 2013-2014. From these, 123 (2.2%) were edentulous and were excluded from the analysis of the prevalence of untreated dental caries. Mean DMFT was 9.7 (± 0.2), and the prevalence of untreated dental caries was 26.0%. The mean % E for each group were: 28.6% (± 0.5) for G1 foods, 4.3% (± 0.1) for G2 foods, 10.1% (± 0.2) for G3 foods and 56.9 (± 0.5) for G4 foods. The mean age was 39.6 (± 0.4) years, while women accounted for 50.8% of the sample. Mean daily energy intake was 2170 kcal (± 17.7).

Table 1 shows the outcome of the bivariable analysis for mean DMFT. Older, less educated and female participants had higher DMFT scores, on average. Differences in race/ethnicity were also significant, while poverty was not. Not being able to get dental care last year was also associated with a higher DMFT, as was a higher body mass index and being a current smoker.

Bivariable analysis of untreated dental caries is shown in Table 2. Age and gender were not associated with this outcome, while remaining socioeconomic variables, access to dental care and ability to get it, smoking status and BMI were associated with the prevalence of untreated dental caries.

Table 3 shows associations between DMFT and dietary measures. The only NOVA group associated with DMFT was processed culinary ingredients, with a higher DMFT at the top tertile. Total energy intake was inversely associated with mean DMFT. No crude estimates were statistically significant. After adjustment, processed food dietary contribution in the second (RR 0.92; 95% CI 0.87-0.98) and the fourth (RR 0.89; 95% CI 0.84-0.94) quartiles of G3%E were associated with lower DMFT. Consumption of unprocessed or minimally processed foods was not associated with any of the outcomes in our study. A higher intake of processed culinary ingredients also was associated with fewer decayed surfaces (RR 0.66; 95% CI 0.44-0.99). Consumption of ultra-processed foods was associated with caries experience at its top quartile (RR 1.10; 95% CI 1.04-1.16) after adjustment for confounders.

Associations between untreated caries and dietary measures are presented in Table 4. A higher dietary contribution of unprocessed or minimally processed foods and a higher dietary contribution of processed foods were associated with lower prevalence of untreated dental caries, while no association was found with the intake of processed culinary ingredients or ultra-processed foods. Total

TABLE 2 Prevalence of untreated caries by sociodemographic and health characteristics in the NHANES cycles 2011-2014

	No. participants	% Untreated Caries	*P*-value[a]
Total	5597	26.0%	
Age group			
20-29	1431	29.0	
30-39	1414	28.6	
40-49	1408	23.2	
50-59	1344	23.0	.334
Sex			
Male	2682	26.9	
Female	2915	25.1	.298
Race/ethnicity			
Non-Hispanic white	2170	21.9	
Mexican American	706	35.7	
Other Hispanic	511	28.6	
Non-Hispanic black	1278	40.7	
Non-Hispanic Asian	722	16.1	
Other race—including multi-racial	210	32.1	<.001
Family Income-to-Poverty Threshold Ratio			
>1	3952	21.6	
≤1	1257	45.9	<.001
Education			
Less Than 9th Grade	274	44.0	
9-11th Grade	678	48.2	
High School Grad/ GED or Equivalent	1160	38.7	
Some College or Associate degree	1850	26.1	
College Graduate or above	1633	9.9	<.001
Last dental visit			
Within last year	3069	16.5	
More than 1 year but less than 5 years	1722	35.0	
More than 5 years, never or does not know	806	50.9	<0.001
Could not get dental care (last year)			
Yes	1362	52.2	
No	4136	18.5	<.001
Body Mass Index			
Underweight	91	26.2	
Normal	1635	22.8	
Overweight	1737	22.6	
Obesity	2105	31.7	<.001
Smoking status			
Never smoker	3429	20.2	
Ex-smoker	962	21.3	
Current smoker	1203	46.5	<.001

[a]Chi-square test.

energy intake was not associated with it either. In unadjusted models, both unprocessed and minimally processed and processed foods were associated with lower prevalence of untreated caries, while the top quartile of ultra-processed food contribution was strongly associated with higher prevalence. After adjustment, all of these associations lost statistical significance. Overall, no clear gradients were found in any of the adjusted models for any of the groups.

4 | DISCUSSION

In an analysis of nationally representative data from the United States of America, we found that consumption of ultra-processed foods is associated with a higher DMFT, while intake of processed foods is associated with lower DMFT. No associations between any of the NOVA groups and the outcome of untreated dental caries were observed. While we found some moderately sized association measures in crude analysis, both for DMFT and prevalence of untreated caries, they were eliminated or mostly attenuated when controlling for covariates. No consistent gradients were found either, suggesting, at least in this sample, that there is no linear association between exposures and outcomes.

This study shares its limitations with those of NHANES dietary components. While two 24-hour recalls were performed according to the five-step FDA validated method in order to obtain more robust dietary intake estimates, recall bias and some imprecision should be taken into consideration. Additionally, as the NHANES recall was not designed specifically to classify foods into NOVA, misclassification errors may have occurred, which could under or overestimate dietary contribution of certain groups. The oral health examination also has specific limitations. The absence of indicators on salivary flow is of particular importance, as well as the absence of questions related to protective factors such as fluoride in the questionnaire for adults.

Intake of processed foods (group 3) was associated with lower DMFT. These foods do not contribute to a high share of added sugar intake in the diet, both because their %E is generally low and also because foods in this group do not carry a large amount of added sugars.[4] Processed foods are cheeses, ham and other cured meats, pickled vegetables, preserves and jams, salted or sugared nuts, peanut or other nut spreads and fermented alcoholic beverages.[4,23] It could be that this protective factor is merely a reflection of

TABLE 3 Association between DMFT index and daily energy intake contribution quantiles for each NOVA group and total energy intake, NHANES, 2011-2014

	Quantile range	N	DMFT (± SE)	DMFT – Rate Ratio (95% Confidence interval)	
				Crude	Adjusted[a]
Unprocessed or minimally processed foods					
Quartile 1 (reference)	0.0-17.5	1275	9.9 (0.3)		
Quartile 2	17.6-26.6	1302	10.0 (0.2)	1.02 (0.96-1.07)	1.00 (0.94-1.06)
Quartile 3	26.7-37.7	1364	9.5 (0.3)	0.97 (0.89-1.05)	0.98 (0.93-1.05)
Quartile 4	37.8-98.3	1779	9.6 (0.3)	0.97 (0.90-1.06)	0.98 (0.93-1.02)
Processed culinary ingredients					
Tertile 1 (reference)	0.0-1.9	1774	9.6 (0.3)[b]		
Tertile 2	2.0-5.1	1913	9.5 (0.4)[b]	1.01 (0.92-1.12)	0.99 (0.93-1.06)
Tertile 3	5.1-51.5	2033	10.1 (0.2)[b]	1.06 (1.00-1.14)	0.99 (0.94-1.05)
Processed foods					
Quartile 1 (reference)	0.0-3.0	1637	10.4 (0.5)		
Quartile 2	3.1-7.6	1529	9.4 (0.4)	0.89 (0.81-0.98)	0.92 (0.87-0.98)
Quartile 3	7.7-14.6	1348	9.9 (0.2)	0.94 (0.85-1.03)	0.94 (0.88-1.01)
Quartile 4	14.7-76.6	1206	9.3 (0.3)	0.89 (0.81-0.96)	0.89 (0.84-0.94)
Ultra-processed foods					
Quartile 1 (reference)	0-44.5	1604	9.5 (0.3)[b]		
Quartile 2	44.6-57.7	1415	9.7 (0.3)[b]	0.99 (0.92-1.08)	1.06 (0.99-1.13)
Quartile 3	57.8-69.8	1348	9.8 (0.4)[b]	1.01 (0.92-1.11)	1.05 (0.96-1.15)
Quartile 4	69.9-100	1353	10.0 (0.4)[b]	1.03 (0.95-1.12)	1.10 (1.04-1.16)
Total energy intake					
Quartile 1	96-1617	1556	10.4 (0.3)		
Quartile 2	1618-2039	1349	9.8 (0.4)		
Quartile 3	2040-2609	1373	9.7 (0.4)		
Quartile 4	2610-10 025	1442	9.1 (0.3)		

[a]Adjusted for age, gender, race/ethnicity, poverty-to-income ratio, highest education, last dental visit, ability to get dental care, body mass index, smoking status and total energy intake.
[b]$P < .05$ Kruskal-Wallis test.

proportionately less sugar intake and not due to a intrinsically protective property of foods in this group.[4]

A higher proportional intake of ultra-processed foods was not consistently associated with dental caries. Crude associations were significant and of moderate strength, but they were completely eliminated after controlling for selected confounders. Untreated caries was relatively common in our sample, and it was mostly associated with socio-economical and access to care aspects. In the United States, intake of ultra-processed foods is higher in less advantaged population, in particular the poorer and the younger, which also presented more untreated dental caries.[27] It falls beyond the scope of this study to assess whether the relation between dental caries and socioeconomic status is one of mediation or simply a case of confounding. Nonetheless, these findings go against recent observations of associations between untreated dental caries and measures of dietary quality, even in controlled models.[28]

Despite the lack of association with untreated caries, the intake of ultra-processed foods was associated with caries experience in controlled models, albeit weakly and only when comparing the first against the fourth quartile. The most important dietary risk factor for dental caries is the amount of sugar consumed, and while %E of ultra-processed drives most added sugar intake, this correlation is not 1:1.[4] It could be that individuals with slightly lower %E of ultra-processed foods would be exposed to a higher amount of sugar, and in this scenario, this exposure variable would not be such a strong predictor of DMFT. NOVA classification has some sugary items spread across the different groups,[23] and while they are not so clearly correlated with total added sugar intake, they may nonetheless make an important contribution to caries development. A cariostatic effect of dietary fat[29] could also contribute to a weak association between %E of ultra-processed food and caries, since many ultra-processed foods are rich in fat. Additionally, the proportion of daily energy intake as a measure of exposure is limited in the sense that it does not account for the absolute number of

TABLE 4 Association between untreated caries and daily energy intake contribution quantiles for each NOVA group, NHANES, 2011-2014

	Quantile range	N	% Untreated Caries	Untreated caries—Odds Ratio (95% Confidence interval)	
				Crude	Adjusted[a]
Unprocessed or minimally processed foods					
Quartile 1 (reference)	0.0-17.5	1241	29.9[b]		
Quartile 2	17.6-26.6	1272	28.4[b]	0.93 (0.72-1.19)	1.21 (0.89-1.63)
Quartile 3	26.7-37.9	1349	22.3[b]	0.67 (0.55-0.82)	0.89 (0.69-1.14)
Quartile 4	38.0-98.3	1735	23.4[b]	0.72 (0.57-0.91)	1.13 (0.88-1.45)
Processed culinary ingredients					
Tertile 1 (reference)	0-1.9	1735	28.1		
Tertile 2	2.0-5.1	1881	24.2	0.82 (0.65-1.02)	0.80 (0.63-1.03)
Tertile 3	5.2-51.5	1981	25.7	0.89 (0.73-1.07)	0.90 (0.76-1.06)
Processed foods					
Quartile 1 (reference)	0.0-3.0	1614	32.6[b]		
Quartile 2	3.1-7.6	1484	25.2[b]	0.70 (0.58-0.84)	0.88 (0.72-1.08)
Quartile 3	7.7-14.6	1311	22.7[b]	0.61 (0.50-0.74)	0.89 (0.67-1.17)
Quartile 4	14.7-76.6	1188	23.5[b]	0.64 (0.50-0.81)	0.96 (0.73-1.27)
Ultra-processed foods					
Quartile 1 (reference)	0.0-44.5	1576	22.2		
Quartile 2	44.6-57.7	1386	23.9	1.10 (0.86-1.40)	0.95 (0.69-1.32)
Quartile 3	57.8-69.7	1320	26.6	1.27 (0.99-1.63)	0.99 (0.71-1.38)
Quartile 4	69.8-100.0	1315	31.3	1.60 (1.26-2.02)	1.01 (0.78-1.30)
Total energy intake					
Quartile 1	96-1619	1527	26.8		
Quartile 2	1620-2042	1320	24.9		
Quartile 3	2043-2614	1348	22.9		
Quartile 4	2615-10 025	1402	29.5		

[a]Adjusted for age, gender, race/ethnicity, poverty-to-income ratio, highest education, last dental visit, ability to get dental care, body mass index, smoking status and total energy intake.

[b]$P < .05$ Kruskal-Wallis test.

kilocalories of ultra-processed foods consumed. We have decided to control for total calorie intake, even though is arguable that a higher energy intake could be approached as a mediator and not a confounder, due to it being caused by a diet rich in ultra-processed foods.[8] Another issue is the exceptionally high levels of ultra-processed %E in the US diet and, conversely, the low levels of unprocessed %E. The dose-response curve for caries is proposed to be sigmoid at its right-hand extremity,[14,15] and it is likely that, at these levels of intake, the great majority of the population has reached the plateau of this curve. Borrowing from Rose's concept of 'sick individuals and sick populations',[30] this would explain the %E of ultra-processed foods potentially being a poor individual predictor of caries. In this sense, deriving thresholds of ultra-processed %E that communicate with the WHO added sugar recommendations could yield informative results. Additionally, one of the largest contributors to the levels of unprocessed %E is cereals, which include forms of refined starches. These starches can cause caries, even if not with the same intensity as sugars.[16] The level of fluoride exposure in the United States should also be taken into consideration. Around three-quarters of the US population is served by fluoridated drinking water,[31] a known confounder in the sugar-caries association.[19,20]

This study aimed to investigate, in a nationally representative sample of USA adults, whether proportional consumption of foods in each NOVA group was associated with dental caries. Higher proportional intake of some of these groups is only weakly associated with dental caries in the adult population of the USA. Of particular interest are the weak positive associations between intake of ultra-processed foods and these outcomes. Further research in populations with less widespread exposure to ultra-processed foods and the development of thresholds of ultra-processed %E should make clear whether these results are due to a weak effect of ultra-processed foods on caries or due to only small variations in the level of intake of these foods in the US population.

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CONFLICT OF INTEREST

None declared.

AUTHOR CONTRIBUTION

Augusto Bacelo Bidinotto conceptualized the study, contributed to methodology and formal analysis, and wrote the original draft—review and editing. Eurídice Martinez Steele conceptualized the study, curated the data, contributed to methodology, and wrote the manuscript—review and editing. Joana Cunha-Cruz conceptualized the study and wrote the manuscript—review and editing. William Murray Thomson conceptualized and wrote the manuscript—review and editing. Fernando Neves Hugo conceptualized the study, contributed to methodology, and wrote the manuscript—review and editing. Juliana Balbinot Hilgert conceptualized the study, contributed to methodology, supervised the study, and wrote the manuscript—review and editing.

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REFERENCES

1. Monteiro CA, Moubarac J-C, Cannon G, Ng SW, Popkin B. Ultra-processed products are becoming dominant in the global food system. *Obes Rev*. 2013;14(Suppl 2):21-28.
2. Vandevijvere S, Jaacks LM, Monteiro CA, et al. Global trends in ultraprocessed food and drink product sales and their association with adult body mass index trajectories. *Obes Rev*. 2019;20(Suppl 2):10-19.
3. Moubarac J-C, Parra DC, Cannon G, Monteiro CA. Food Classification Systems Based on Food Processing: Significance and Implications for Policies and Actions: A Systematic Literature Review and Assessment. *Curr Obes Rep*. 2014;3(2):256-272.
4. Martínez Steele E, Baraldi LG, da Costa Louzada ML, et al. Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study. *BMJ Open*. 2016;6:e009892.
5. Martínez Steele E, Popkin BM, Swinburn B, Monteiro CA. The share of ultra-processed foods and the overall nutritional quality of diets in the US: evidence from a nationally representative cross-sectional study. *Popul Health Metr*. 2017;15(1):6.
6. Machado PP, Steele EM, da Costa Louzada ML, et al. Ultra-processed food consumption drives excessive free sugar intake among all age groups in Australia. *Eur J Nutr*. Published online. 2019.
7. Rauber F, da Costa Louzada ML, Martinez Steele E, et al. Ultra-processed foods and excessive free sugar intake in the UK: a nationally representative cross-sectional study. *BMJ Open*. 2019;9:e027546.
8. Hall KD, Ayuketah A, Brychta R, et al. Ultra-Processed Diets Cause Excess Calorie Intake and Weight Gain: An Inpatient Randomized Controlled Trial of Ad Libitum Food Intake. *Cell Metab*. 2019;30(1):67-77.e3.
9. Fiolet T, Srour B, Sellem L, et al. Consumption of ultra-processed foods and cancer risk: results from NutriNet-Santé prospective cohort. *BMJ*. 2018;360:k322.
10. Martínez Steele E, Juul F, Neri D, Rauber F, Monteiro CA. Dietary share of ultra-processed foods and metabolic syndrome in the US adult population. *Prev Med*. 2019;125:40-48.
11. de Mendonça RD, Lopes ACS, Pimenta AM, Gea A, Martinez-Gonzalez MA, Bes-Rastrollo M. Ultra-Processed Food Consumption and the Incidence of Hypertension in a Mediterranean Cohort: The Seguimiento Universidad de Navarra Project. *Am J Hypertens*. 2017;30(4):358-366.
12. Schnabel L, Kesse-Guyot E, Allès B, et al. Association Between Ultraprocessed Food Consumption and Risk of Mortality Among Middle-aged Adults in France. *JAMA Intern Med*. 2019;179(4):490-498.
13. Rico-Campà A, Martínez-González MA, Alvarez-Alvarez I, et al. Association between consumption of ultra-processed foods and all cause mortality: SUN prospective cohort study. *BMJ*. 2019;365:l1949.
14. Moynihan PJ, Kelly SAM. Effect on Caries of Restricting Sugars Intake: Systematic Review to Inform WHO Guidelines. *J Dent Res*. 2014;93(1):8-18.
15. Sheiham A, James WPT. A reappraisal of the quantitative relationship between sugar intake and dental caries: the need for new criteria for developing goals for sugar intake. *BMC Public Health*. 2014;14:863.
16. Halvorsrud K, Lewney J, Craig D, Moynihan PJ. Effects of Starch on Oral Health: Systematic Review to Inform WHO Guideline. *J Dent Res*. 2019;98(1):46-53.
17. World Health Organization. *Guideline: Sugar Intake for Adults and Children*. World Health Organization; 2015.
18. Brasil. *Guia alimentar para a população Brasileira* (2nd ed). Ministério da Saúde, Secretaria de Atenção à Saúde, Departamento de Atenção Básica; 2014.
19. Sheiham A. Dietary effects on dental diseases. *Public Health Nutr*. 2001;4(2B):569-591. https://doi.org/10.1079/PHN2001142
20. Moynihan P, Petersen PE. Diet, nutrition and the prevention of dental diseases. *Public Health Nutr*. 2004;7(1A):201-226.
21. National Center for Health Statistics (U.S.). *National Health and Nutrition Examination Survey. Analytic Guidelines, 2011–2014 and 2015–2016*. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics; 2018.
22. Centers for Disease Control. *National Health and Nutrition Examination Survey: MEC In-Person Dietary Interviewers Procedures Manual*; 2010.
23. Monteiro CA, Cannon G, Levy R, et al. NOVA. The star shines bright. [Food classification. Public Health]. *World Nutr*. 2016;7(1–3):11.
24. Juul F, Martinez-Steele E, Parekh N, Monteiro CA, Chang VW. Ultra-processed food consumption and excess weight among US adults. *Br J Nutr*. 2018;120(1):90-100.
25. Centers for Disease Control. *National Health and Nutrition Examination Survey: Oral Health Examiners Manual*; 2011.
26. Lumley T. Analysis of Complex Survey Samples. *J Stat Softw*. 2004;9(8):1-19.
27. Baraldi LG, Steele EM, Canella DS, Monteiro CA. Consumption of ultra-processed foods and associated sociodemographic factors in the USA between 2007 and 2012: evidence from a nationally representative cross-sectional study. *BMJ Open*. 2018;8:e020574.

28. Kaye EA, Sohn W, Garcia RI. The Healthy Eating Index and coronal dental caries in US adults. *J Am Dent Assoc*. 2020;151(2):78-86.
29. Giacaman RA. Sugars and beyond. The role of sugars and the other nutrients and their potential impact on caries. *Oral Dis*. 2018;24(7):1185-1197.
30. Rose G. Sick individuals and sick populations. *Int J Epidemiol*. 2001;30(3):427-432.
31. Slade GD, Grider WB, Maas WR, Sanders AE. Water Fluoridation and Dental Caries in U.S. Children and Adolescents. *J Dent Res*. 2018;97(10):1122-1128.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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